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## Curriculum Vitae

**Name:** Dr. R. Mukund

**Date of Birth:** 19 May 1961

**Educational Qualifications:**

PhD, Aerospace, Indian Institute of Science, Bangalore, 2003

M.Sc (Engg. Res), Mechanical, Indian Institute of Science, Bangalore, 1989

B.E. Mechanical, Bangalore University, 1984



**Professional experience:**

Twenty years experience in NAL as scientist in the area of experimental aerodynamics, low speed and high speed wind tunnel measurements and measurement techniques

**Research Interests:**

- » Boundary layers
- » Relaminarization
- » Propeller flows
- » Oscillating airfoils
- » Low Reynolds number flows
- » Micro-Aerial Vehicles

**Awards / Honors received:**

CSIR Raman Research Fellowship 2006-2007 and deputed to DLR, Gottingen, Germany

## Wind tunnel measurements on MAV planforms

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Micro-aerial vehicles (MAV) are being developed all round the world for a variety of civilian and military purposes. NAL has taken up a project to develop a fixed wing MAV of 300mm size weighing nearly 300gm capable of flying for 20-30 minutes in autonomous flight, with optical and transmission devices as payload. The aerodynamics of the MAV [1-3] having restricted span and flying at low Reynolds numbers is much different from that of a typical aircraft. These MAVs have a near circular wing planforms similar to the one designed by Zimmermann [4] and have a sharp leading edge and thin cambered sheet instead of a thick airfoil. Several such MAVs have been designed and successfully flown all over, however the flow over the MAVs wing is not well understood especially the mechanism of obtaining lift at high incidences. Further, established design procedures do not exist for MAV as for conventional aircrafts. Computation of such complicated low Reynolds number flows is rather difficult. Thus experimental studies are of utmost importance for not only understanding the flow but also to optimize the design.

An experimental study was taken up in the 1.5m wind tunnel at NAL to characterize combinations of different planforms like those by Zimmermann and camberline distributions. Different planforms (Fig.1.) fabricated out of composite, of mid chord 280mm, span 300mm and of constant thickness  $\cong 1$ mm were mounted on a standard fuselage in regular or inverse configurations. Initially, the planforms were thin flat plates without camber (designated C0) and later the camber-line distribution of airfoils Selig 4083 (C1), Selig 5010 (C2) having reflex camber and MH15 (C3) were studied.

Using a specially designed three-component strain-gage balance having low capacity (1kg), force measurements were conducted on all the models at freestream velocities  $U_\infty$  of 8, 10 and 12 m/s for a angle of attack ( $\alpha$ ) range of  $-10^\circ$  to  $38^\circ$ . Selected results of the measurements at 12m/s, shown in Fig.2. The first two characters of the legend give the camber and the rest give the planform and 'I' stands for inverse. These results agree with the previous studies in that the lift curve becomes non-linear for above  $\alpha = 6^\circ$ . The nonlinearity was attributed increasing strength of the wing-tip vortices with  $\alpha$ . The presence of the vortices avoided separation and increased the stall angle to as high as  $35^\circ$  on our models. For the flat planforms (Fig.2a,2c), as compared to the Zimmermann (Z), our new planforms MZ, NZ and NZI had not only greater area but also showed higher coefficient of lift  $C_L$ , the lift of MZ continuing to increase up to  $38^\circ$ . The drag coefficient  $C_D$  also increased as expected.

Among the cambered planforms, (Fig.2b,2d), MZ planform with S4083 camber (C1MZ) showed better lift and higher drag than other wings. All the inverse planforms with camber underwent hysteresis beyond  $\alpha=25^\circ$  and all the rest did not do so. These results show the complex nature of the flow in this range of Reynolds number.

Pressure measurements and flow visualization were conducted to understand the dynamics of the flow. The results of these visualization studies will be presented at the workshop.

## References

1. Selig M.S, Guglielmo J.J, Broern A.P and Giure P. (1996) *Experiments on Airfoils at Low Reynolds Numbers*, AIAA Paper 96-0062.
2. Mueller T.J. (1999) *Aerodynamic Measurements at Low Reynolds Number for Fixed Wing Micro Air Vehicles*, RTO AVT/VKI Special Course on 'Development and Operation of UAVs for Military and Civil Applications, VKI, Belgium.
3. Mueller T. J. et al. (2007) *Introduction to the Design of Fixed-Wing Micro Air Vehicles Including Three Case Studies*, AIAA Education Series.
4. Zimmerman C. H. (1935) *Aerodynamic characteristics of several airfoils of low aspect ratio*, NACA TN 539.

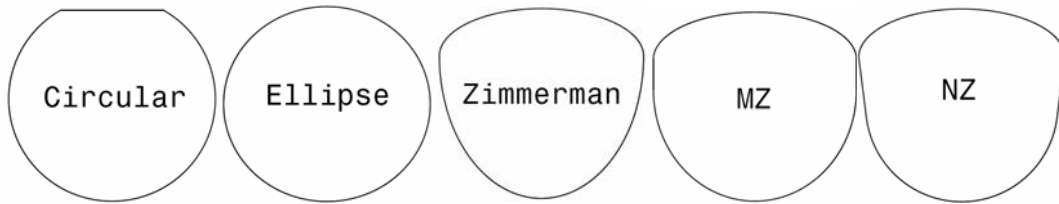


Fig.(1). The planforms used for aerodynamic characterization

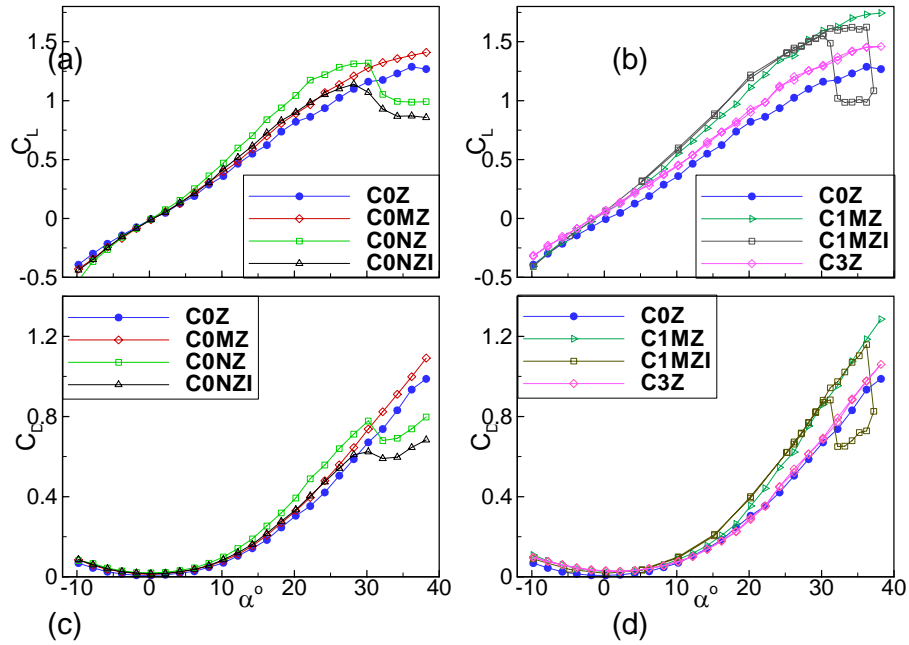


Fig.2(b-e) Aerodynamic characteristics at  $U_\infty = 12 \text{ m/s}$  on flat (a,c) and cambered (b,d) planforms